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"The Distributed Cognitive Components of C2"

Topic 4: Cognitive and Social Issues

Topic 1: C2 Concepts, Theory, & Policy

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14. ABSTRACT
Distributed cognition (Hutchins, 1995a) is a theoretical framework that explains cognitive activities embodied and situated within the work setting and the artifacts used in the environment. Distributed cognition emphasizes the distributed nature of cognitive phenomena across individuals, tools/technologies, and internal/external representations. The unit of analysis goes beyond the cognitions of a single individual and focuses on the functional system as a whole. Distributed cognition examines the relation between individuals, the task environment, and artifacts used for task completion. Among some of the distributed cognitive attributes are: 1) Coordination across agents; 2) situation assessment; 3) mental models; 4) memory demands; 5) adaptability; and 6) workload management. Command & Control (C2) systems can greatly benefit when examined and analyzed as a distributed cognitive system through its emphasis on these cognitive attributes of the system. The theoretical and analytical implications of applying this approach to C2 systems will be discussed based on recent application and analysis to a series of C2 experiments.

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The Distributed Cognitive Components of C2

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Abstract

Distributed cognition (Hutchins, 1995a) is a theoretical framework that explains cognitive activities embodied and situated within the work setting and the artifacts used in the environment. Distributed cognition emphasizes the distributed nature of cognitive phenomena across individuals, tools/technologies, and internal/external representations. The unit of analysis goes beyond the cognitions of a single individual and focuses on the functional system as a whole. Distributed cognition examines the relation between individuals, the task environment, and artifacts used for task completion. Among some of the distributed cognitive attributes are: 1) Coordination across agents; 2) situation assessment; 3) mental models; 4) memory demands; 5) adaptability; and 6) workload management. Command & Control (C2) systems can greatly benefit when examined and analyzed as a distributed cognitive system through its emphasis on these cognitive attributes of the system. The theoretical and analytical implications of applying this approach to C2 systems will be discussed based on recent application and analysis to a series of C2 experiments.

Keywords: Command and control, distributed cognition, coordination, situation awareness, mental models, workload

Distributed Cognition Framework

One of the challenging aspects of studying command and control (C2) is its complexity, including the complexity of the task, organization, and tools. A theoretical framework that aids in understanding and analyzing C2 complexity across these areas is the distributed cognition framework (Hutchins, 1995a). This framework applies the cognitive characteristics traditionally applied to an individual and generalizes it across individuals, tools, and the task environments. By expanding cognition outside of a single individual's mind, distributed cognition connects several fields of study to cognition including social, human factors, and environmental psychology theories. This paper will provide an overview of distributed cognition along with a description and examples of its application to the area of C2 with the overall intent of expanding the theoretical base of C2 research.

Distributed Cognition across Individuals

Distributed cognition connects cognitive science to several other fields that include social, human factors, and environmental psychology. The bridge for the often-implied

gap between cognitive and social theories of science is made by expanding investigation of cognition to multiple individuals and their task related interactions (Giere, 2002). The distributed cognitive approach assumes that the cognitive processes of groups will differ from that of an individual. When applied to the cognitive component of memory, distributed cognition is illustrated through the theory of transactive memory.

Transactive memory typically occurs among individuals with close associations and frequent interactions (Wegner, *et al.*, 1991). These relationships help develop a shared system for knowledge storage and retrieval that provides an overall memory and knowledge system that is greater than any of the individuals comprising it. Individuals within the system essentially act as external memory aids to one another with a distinction between internal and external representation of information. For example, a husband may not recall the phone number to his mother-in-law but knows to refer to his wife for this information when needed. The collective capacity for memory storage and retrieval provides benefits in efficiency (Moreland, *et al.*, 1998), accurate recognition of expertise (Henry, 1995), and better group performance through training (Liang, *et al.*, 1995).

Distributed Cognition across Artifacts

Distributed cognition also expands what is traditionally considered cognitive beyond the individual and groups to also include the artifacts being used by the individual and/or group. The interaction between the user and the artifact/tool being used in goal directed tasks typically falls under the field of human factors psychology, particular within human-computer interaction. Donald Norman (1988) defined knowledge in the head and knowledge in the world to help define the interaction between the user and artifacts in the environment.

Knowledge in the head refers to the typical conception of internal memory within cognitive science. Knowledge in the world, however, refers to information that is represented external to an individual like phone numbers in a personal digital assistant (PDA) and therefore does not require cognitive resources to encode, store, and retrieve from memory when needed. It does however, require memory of where that information can be retrieved when needed. The nature of having this knowledge ‘in the head’ vs. ‘in the world’ is quite different in terms of recall speed, reliability, capacity, and multi-tasking performance to name only a few (Hutchins, 1995b). These are all important elements to consider and understand when studying and evaluating C2 systems. The consideration of these elements for the functional system that spans across individuals and artifacts is accomplished through the distributed cognition framework.

Distributed Cognition across Environments

The third gulf that distributed cognition bridges is that of the environment and its importance in the study of the elements mentioned above. With roots in Gibson’s (1950) theories on the ecological approach to visual perception and the small but growing field of environmental psychology, the task environment provides context and meaning for the person-to-person and person-to-artifact interactions already discussed. The importance of

considering the complex and dynamic nature of the environment is highlighted by Simon's parable of the ant on the beach (Simon, 1969). Simon maintained that the complexity in an ant's path on a beach is not due to the ant, which is a fairly simple behavioral system, but is due to the complexity and variability of the beach itself. Environmental factors such as stress, workload, noise, and time pressure are all known to be factors on C2 related performance metrics like collaboration, communication, and decision making (e.g., Huey & Wickens, 1993; Reason, 1990). Again, these are all important factors to consider in the study of C2 systems that the distributed cognition framework facilitates.

Past Domain Applications of Distributed Cognition

Distributed cognition has been applied to a number of different domains and tasks in prior research. The focus on the distributed, socio-technical system as the primary unit of analysis instead of the individual mind provides a unique and often a more comprehensive analysis and understanding of the task, tools, and individuals involved.

Hutchins applied the distributed cognition framework to the field of aviation by showing "how the cockpit system performs the cognitive tasks of computing and remembering a set of correspondences between airspeed and wing configuration" (1995b, p. 266). This involved the integration of pilots, their physical surroundings, and tools working as one functional system. For example, the speed card booklet in the cockpit is a long-term memory aid in the system as it is a permanent representation of data. It is also displayed and shared by both pilots for use anytime during the decent. A speed bug is a physical element that represents the memory of the speed in which the wing configuration changes. Speed bugs transform and simplify the cognitive processes used by pilots from one of retaining the specific speeds in working and/or long-term memory and retrieving them when needed to perform a simple spatial judging task. For instance, pilots know that when the speed needle approaches a speed bug, a new wing configuration change is needed (Figure 1).

Speed bugs as shown in Figure 1 extend beyond a memory aid for the pilots, as they are a memory property of a larger system, the cockpit system. This is a basis of distributed cognition in which the memory of the cockpit is not made up of just pilot memory. The robustness and endurance of the speed bug memory is much more efficient than individuals trying to store the same information in working or long-term memory and attempting to retrieve it during times of high mental workload and/or stress. Hutchins postulates that theories of individual human memory do not explain how this or other systems work but explains why they work. To answer the 'how' question, a broader, more comprehensive examination must be done that encompasses other integral parts of the functional system as done with the cockpit system here.

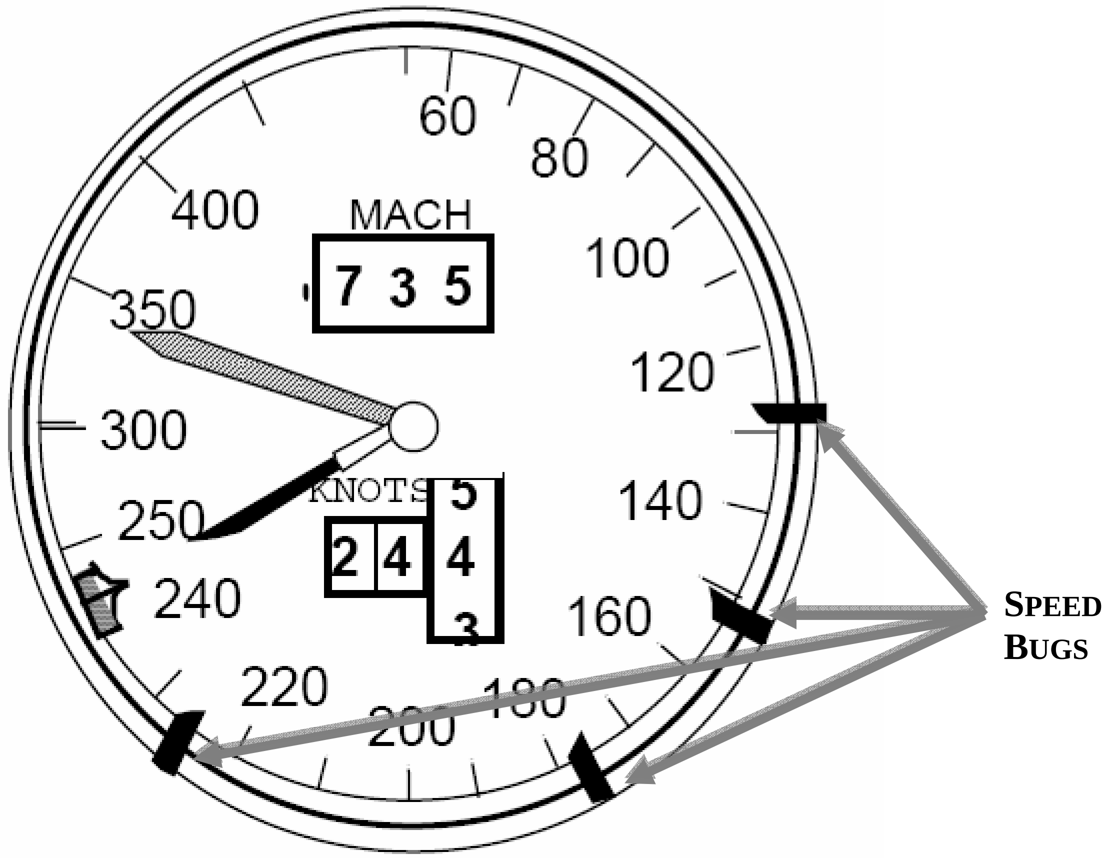

Figure 1. Speed bugs. Illustrated from the speed indicator instrument from the McDonnell Douglas MD-80 described by Tenney, 1988 (Hutchins, 1995).

Distributed Cognition Framework Applied to C2

Distributed Cognitive System Attributes

Continuing efforts to identify and define the critical attributes of a distributed cognitive system have made it easier to measure and understand distributed cognitive systems (Hansberger, *et al.*, in press). The primary attributes of a distributed cognitive system consist of: 1) Coordination across agents; 2) situation assessment; 3) mental models; 4) memory demands; 5) workload management, and 6) adaptability. The identification of these attributes has origins from Woods, *et al.*, (1994) and has been updated and modified to its current form by the author.

Briefly, the coordination across agents attribute addresses person-to-person and person-to-artifact interactions within the task environment. The situation assessment attribute relies heavily on the situation awareness literature (e.g., Endsley, 1995) and considers both the situation assessment process of acquiring information about the environment and the situation assessment product of achieving a state of awareness of the acquired information (Tenney, *et al.*, 1992). The mental model attribute refers to the representation

of knowledge and its network of relationships built over time to help guide and direct behavior and decision-making (e.g., Johnson-Laird, 1983).

The memory demands attribute deals with the memory requirements for a task and the speed and reliability of the encoding, storing, and retrieval processes. The workload management attribute focuses on the level of workload for a task or series of tasks and the factors that may affect this workload like various strategies, organizational structures, and standard operating procedures. The final attribute focuses on adaptability and how well the individual or system can change behavior in response to the variability in a dynamic environment to maintain or improve performance (Hansberger, *et al.*, 2006).

Basic C2 Functions

Command and control is a diverse and complex area, which makes it challenging to define and measure. For the purpose of this research, C2 is defined as, "The establishment of common intent to achieve coordinated action." (Pigeau & McCann, 2000, p. 165). To further define the C2 area, the eight C2 functions identified by Van Creveld (1985) will be used to break C2 down into its primary functional components:

1) Gathering information on relevant situational elements (personnel, equipment, transportation, supplies, etc…)

2) Data manipulation – finding means to store, retrieve, filter, classify, distribute, and display the information

3) Situational understanding

4) Establishing intent – Laying down objectives and working out alternative means for attaining them

5) Decision-making – Deciding what to do

6) Planning

7) Writing orders and transmitting them as well as verifying their arrival and proper understanding by the recipients

8) Monitoring the execution by means of feedback, at which the process repeats itself

Integration of Distributed Cognitive Attributes and C2 Functions

Each of the eight C2 functions has multiple attributes and characteristics associated with them. The distributed cognitive system attributes mentioned above can be aligned with the C2 functions to direct and guide C2 research and measurement. Even though the distributed cognitive system attributes are general enough for all of them to apply to most distributed tasks, it has proven useful to focus on one or two of the primary contributing

attribute for the targeted C2 function. Table 1 provides the primary distributed cognitive attribute associated with each of the eight primary C2 functions.

Table 1. C2 function and distributed cognitive attribute ontology.

C2 Functions	Primary Distributed Cognitive Attribute
Gathering information on relevant situational elements	Situation assessment
Data manipulation	Workload management
Situational understanding	Mental models/situation assessment
Establishing intent	Coordination across agents
Decision-making	Mental models/adaptability
Planning	Coordination across agents/adaptability
Writing orders and transmitting them as well as verifying their arrival and proper understanding by the recipients	Coordination across agents
Monitoring the execution by means of feedback, at which the process repeats itself	Situation assessment/memory demands

Aligning the primary distributed cognitive system attributes to the C2 functions connects the theoretical (distributed cognition framework) to the practical (C2 functions). This connection to theory appears to be absent in many C2 research efforts (Crumley & Sherman, 1990; Foster, 1988) when they should be the guiding force behind most C2 research. Kurt Lewin states that, “There is nothing so useful as a good theory” (1951, p. 169). This link provides the theoretical basis to guide experimentation, assessment, and design efforts in the highly complex and sometimes chaotic area of C2 as well leverage on other theoretical work being done on the same and related issues.

Application of Distributed Cognition to C2

The distributed cognition framework has been applied to the assessment of new C2 technology and planning support tools across a number of the C2 functions mentioned above. Its application has guided the experimentation design, data collection techniques and methods, and data analysis plans. A brief summary on two of the C2 functions and

related distributed cognitive system attributes will provide examples of the application of the distributed cognition framework. Further details on these two areas can be found in complimentary papers presented at the 2008 ICCRTS Conference (Hansberger, *et al.*, in press).

Situational Understanding & Mental Models

The C2 function of situation understanding was examined by focusing on how the users' mental models changed over time and with that of an expert through their interactions with new planning technology (Hansberger *et al.*, in press). The mental model attribute was examined through the measurement of structural knowledge among the participants over time. The use of the distributed cognitive framework not only focused analysis on each of the user's mental model of the targeted domain but suggested the examination of similarities across individual mental models and changes over time.

Planning & Coordination across Agents

The C2 function of planning was examined through the coordination across agents attribute of distributed cognitive systems. 'Agents' for this experimental effort were defined as both the human participants engaged in the planning activities with the new planning tools as well as the different planning tools themselves. The coordination and interactions between planning team members and the various tools used were analyzed to understand the distributed cognitive system as a whole. Social network analysis (e.g., Scott, 2000) data was collected and analyzed to understand the patterns of interactions across the human agents as well as across human and planning tool agents (Hansberger, *et al*., in press). The distributed cognitive approach directed examination outside of a simple team plan to both the social (person-person) and the use of tools (person-artifact).

Conclusion

The distributed cognition framework provides a strong and potentially innovative theoretical approach to the field of command and control. Through its consideration of elements outside of traditional cognitive science, it includes aspects of the social, technological, and environmental components into the investigation and analysis of C2 systems. It is early in the application of distributed cognition to the field of C2 and many advancements are necessary to continue both theoretical and applied C2 research efforts. New methodologies, techniques, and technology are necessary to better collect, assess, and analyze the various attributes of the C2 distributed cognitive system. C2 researchers are in need of a wide array of such techniques and methods to investigate C2 in all its complexity and depth.

Although distributed cognition provides a potentially useful framework to apply towards C2, the burden is still on the researcher to make the theoretical and applied ties and interpretations back to their respective areas. The burden is actually greater with this approach to interpret C2 functions and actions as it casts a larger net on C2 than a cognitive, social, human factor, or environmental psychology approach would alone.

However, that burden is quickly outweighed by the potential rewards to the scientific study of C2 and applied knowledge for the warfighter.

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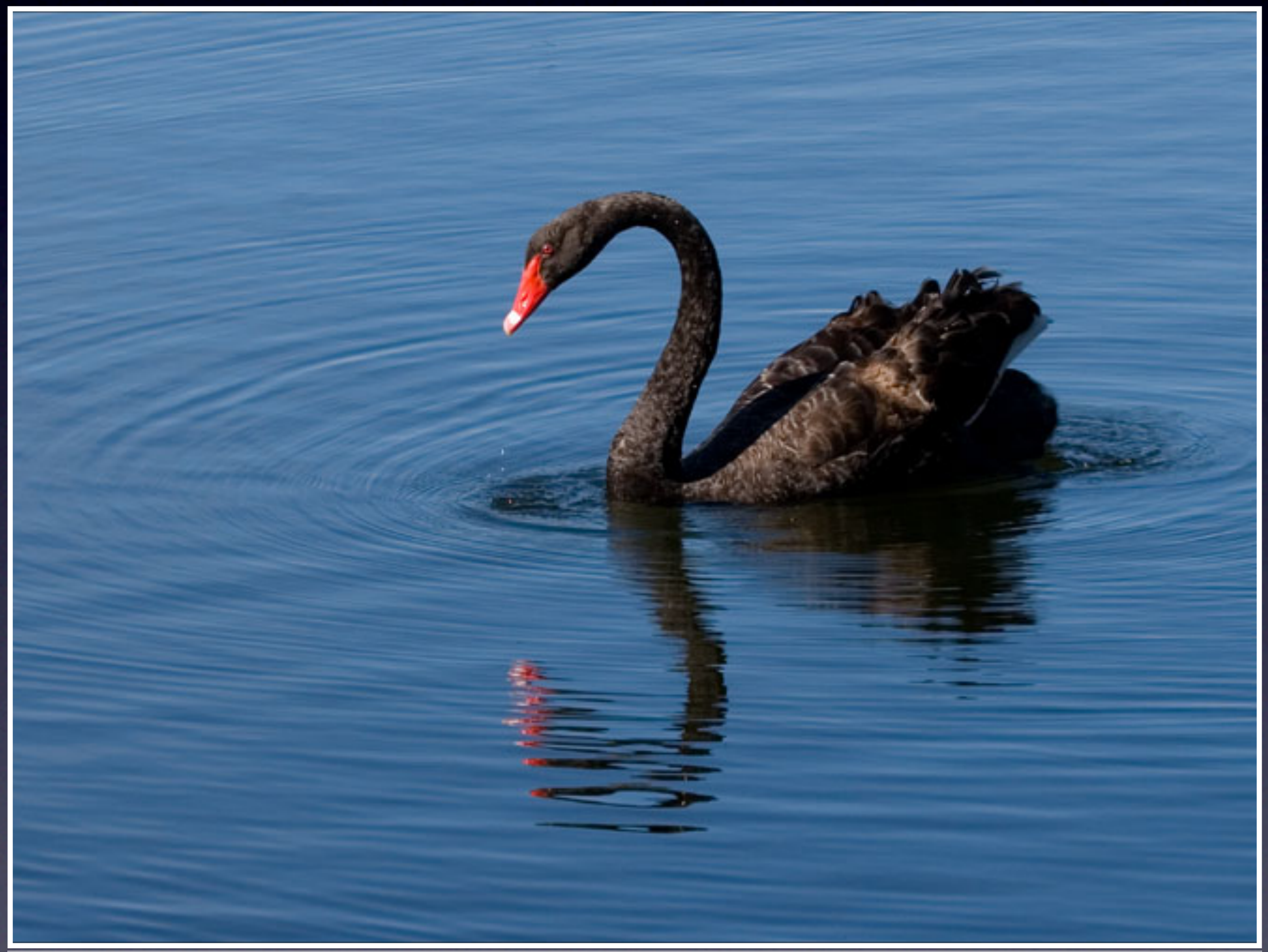
Expectation Management



C2 Video Segment

Gathering Relevant Information

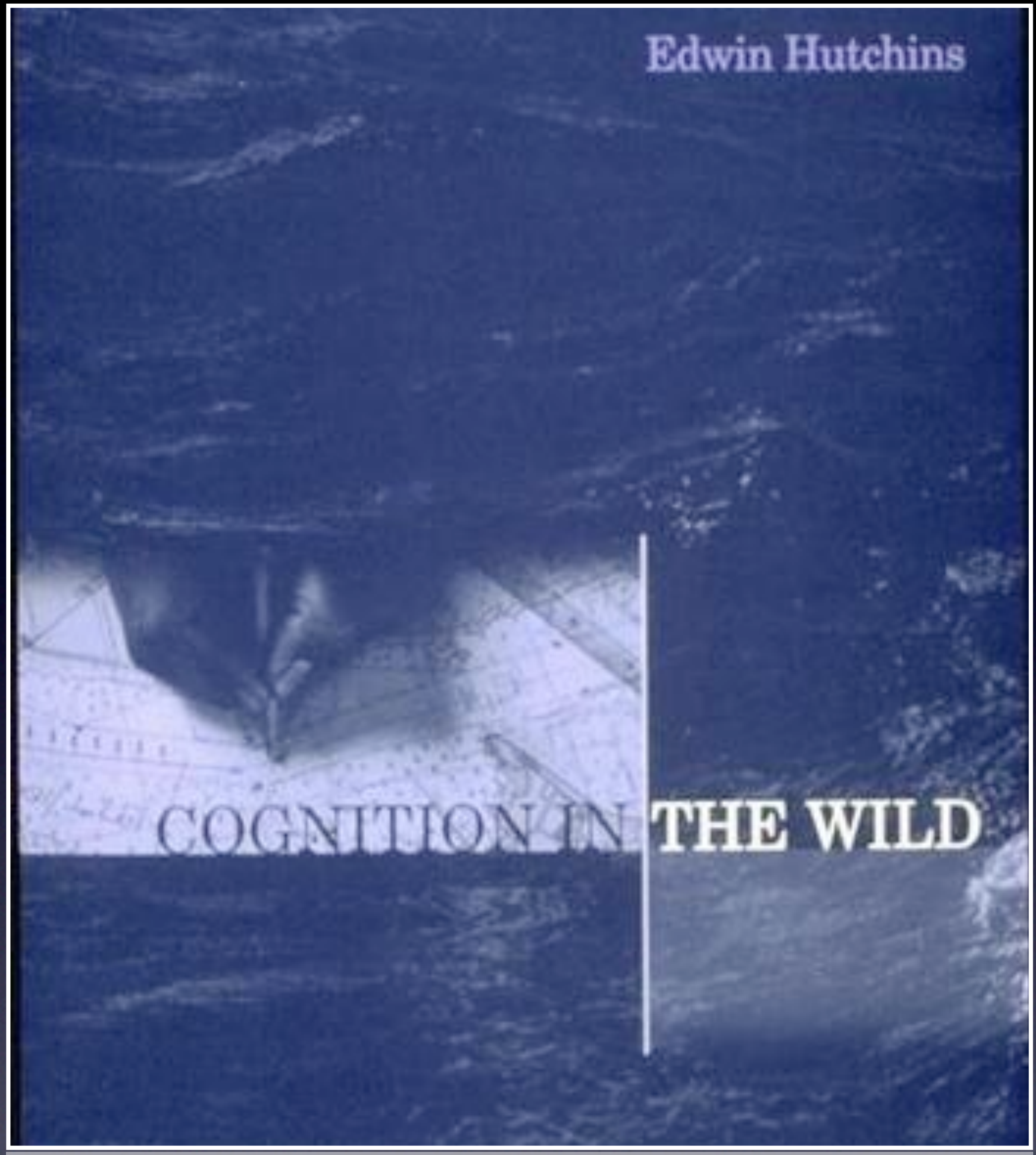
Decision-Making

Planning

Across Individuals

Across Artifacts

Across Environments



Summary

Questions & Comments